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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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No. 443

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DURALUMIN - DEFECTS AND FAILURES

By Lieut. Comdr. Wm. Nelson (CO), U.S.N.

From "Aviation," August 29, 1927

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Washington  
December, 1927

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DURALUMIN - DEFECTS AND FAILURES.\*

By Lieut. Comdr. Wm. Nelson (CC), U.S.N.

One of the advantages of metal over wood as an aircraft material is the uniformity of the metal. There are no shakes, checks, knots, spiral grain, etc., in metal; and, as a consequence, aircraft builders more or less looked forward to the use of duralumin with relief. That their hopes were not entirely confirmed at first resulted from the inherent property of duralumin of having more apparent defects than real ones and from the novelties in the features of the metal. Experience with this aluminum alloy since its introduction to aircraft has tended to set the house in order though, so that at the present time the advantage mentioned is recognized as a factor of importance.

It is proposed in this paper to identify some of the defects and failures in duralumin most frequently encountered by the aircraft industry with a view to indicate their importance. Numerous cases have been called to the writer's attention where the defects have been superficial, whereas, on the other hand, casual inspection has revealed material not fitted for use as structural members in aircraft. To distinguish one

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\*From "Aviation," August 29, 1927.



from the other is not always quite as simple as it seems.

The defects and failures in duralumin may be classified into the following groups:

- a) Defects produced during manufacture of the raw material.
- b) Defects produced during fabrication of the material into parts.
- c) Corrosion and erosion.
- d) Fatigue failures.

Only the first two will be covered in this article since each of the others is far too important to be given other than detailed attention.

The methods of manufacturing duralumin have been so standardized and so rigidly supervised by the producers of this metal that abnormal defects therein are exceptional. Extraordinary efforts by the producers in research and in investigations have been reflected in the material produced so that at the present time the causes of most of the defects occurring are known, and corrective measures are instituted before the material is distributed. However, duralumin is not all that aircraft designers and constructors would like it to be, nor is the product always to be classified as good, for in spite of uniform production and high grade inspection the consumer is sometimes required to make decisions regarding "run of the mill" material.

As is known, duralumin is available in rolled, wrought or extruded form, and in various conditions of thermal treatment.

The rolled duralumin usually leaves the mill with a planished surface, such a surface being produced by the rolling operations. The wrought and extruded forms do not as a rule have the planished appearance, being duller and presenting some evidence of tool action.

Perhaps one of the most widely discussed points regarding duralumin sheet is the question of natural coloring. This material varies in its surface appearance from a clean silvery gray to a dirty gray with all colors of the rainbow superimposed. The clean silvery gray resembles a machined piece in color whereas the dirty gray can be described as dirt rubbed into the metal. When looked at from an angle hues can sometimes be seen on the planished surface varying peculiarly, centering at times in a spot and wandering recklessly at other times. These hues have been described as a copper glint. It has been definitely ascertained by numerous tensile tests that none of these colorings has any bearing on the physical properties of the material nor is the shade of gray a measure of important factors. There are, however, cases where stains on duralumin are accompanied by imperfections in the surface. These imperfections are usually the result of contact with some foreign substance after the material has left the mill. Duralumin so marked should not find its way into aircraft under any circumstances if the surface imperfections, other than the color, are abnormal.



## Raw Material Inspections

The imperfections inspected for on duralumin in the raw state, aside from mechanical properties are laminations, cracks, pits, dirt, scratches, buckles, blisters, slivers, roll marks. Most of these when small have little effect on the physical properties of the material, but are not desirable for other reasons, indicating as they do more serious hidden deficiencies discernible only by the use of a microscope or the X-ray.

Laminations occurring in a part of a sheet or shape have been more frequent in the past than is the case now. Faulty rolling of sheets resulted in a condition where the finished sheet could be separated for a considerable area into two thicknesses with no bond between the two. Fortunately this defect occurs in the edge where it is readily discovered in inspection; but there are cases where the sheets have fitted together so well that laminations were not found until the pressing operation had been completed. Laminations have also been found in tubes, being due to metal in the extrusion block carrying over to the next following extrusion. It seems unnecessary to state that laminated duralumin is not suitable material for aircraft use.

Cracks in sheets and other rolled shapes are due to the temper of the material or to pulling of the rolls. Cracks in the bends of rolled shapes may be due to the thickness radius

of curvature ration being beyond the capacity of the material. Cracks in extruded shapes are usually found at the ends and are caused by the use of more of an ingot than is warranted. Chattering of the die or an imperfection in the die used for extrusion causes a series of cracks readily discernible in the finished product. Although these defects are not admissible in duralumin in general, cracks in tubing should be culled from aircraft material with exactitude. Pits and inclusions can be seen with little difficulty in an otherwise clear duralumin sheet. It is practically impossible to avoid some pits and inclusions in rolled duralumin. Dirt, due to dross or foreign substances picked up by the rolls subsequently rolled into the metal, will appear from time to time and unless the amount is unusual no dire results need be expected. Corrosion does not localize in these pits nor at the inclusion unless it happens to be foreign metal, in which case the corrosion of the duralumin may or may not be hastened. As a rule pits and inclusions are not cause for rejection unless the quantity or frequency warrants such action.

Scratches come through handling of the material. They are not deep enough as a rule to do other than mar the surface, but they have a bearing on corrosion and fatigue failure. Corrosion will concentrate along a scratch if the piece of duralumin is exposed, so it is to the advantage of builders to avoid whenever practicable all scratching in duralumin. Manufacturers of



aluminum alloys now go to great length to reduce mechanical abrasion caused by carelessness in handling; and it is well if storekeepers take equal care to retain the planished surface.

### Buckles Appear in Sheet Stock

Buckles appear in sheet stock in quenching after heat treating. These buckles are wiped out by the strengthening roll which is the last mill operation prior to packing. Buckles in plates involve difficulties in fabricating parts therefrom aside from the effect on appearances.

Slivers may make their appearance as entrained dross, rolled in flakes of metal, or as a thin shell on the sheet or rod. Dross carried over to the rolling operation is drawn out in the direction of rolling and adhered rather firmly to the sheet. The same is true of rolled in flakes of aluminum or duralumin which might be picked up by the rolls. Exfoliation of the ingot on account of the working of the die results in a sliver. Material left in the chamber of an extrusion press by a previous ingot makes its appearance on the extruded shape as a sliver or a thin shell. All types of slivers reduce the value of the product for general use and in case they are extensive no part of the sheet or shape is acceptable. The complete eradication of slivers by brushing or grinding requires the removal of considerable material resulting in a rather diminished dimension for the part affected.

It is believed that blisters should be segregated into two groups; those resulting from normal heat treatment and those resulting from overheating the metal. Blisters on duralumin in the first classification have no effect on the mechanical properties of the material. These blisters are small and not frequent. Blisters that make their appearance on overheated material are a certain indication of changes in the constituents and inferior physical properties accompany such burned metal.

#### Occluded Gas Forms Blisters

In the course of the manufacture of duralumin it can hardly be expected that all occluded gas in the ingot is driven out. Naturally then, a certain portion of that gas will find its way to the surface or near the surface in a sheet or shape. Upon heating the duralumin for heat treatment this gas will tend to expand and in cases form blisters. Heat treating the metal at  $510^{\circ}\text{C}$  will bring them out and it is only by subsequent rolling that the smoothness of the sheet is restored. It is an opinion that sheets displaying a tendency to blister can be culled first prior to the final rolling. Samples of badly blistered sheet have been subjected to induced corrosion and the indications are that no concentration of corrosion at the blisters is effected.

On the other hand, if duralumin is heated to a temperature near  $540^{\circ}\text{C}$ , there is apparently a change in the constitution



of the constituents indicating very strongly the beginning of the melting. This change according to the theory expressed may be accompanied by the formation of melting blisters which in themselves may not be harmful, but they do point out changed physical properties. The usual result of overheating is a perceptible drop in the elongation.

It is not practicable to distinguish between the two kinds of blisters by a visual inspection, so in case an abnormal amount of blistering is occurring it is best to suspect the temperature of heat treatment and if that is correct it is a matter for the makers of the raw material. It is not to the best interests of duralumin to lower the heat treating temperature to reduce blistering effect.

#### Roll Marks Destroy Uniformity

Roll marks are depressions in the direction of rolling that may or may not be accompanied by transverse scratches. These roll marks destroy the continuity and uniformity of the part and should not be unusual in amount. They are caused by improper design of rolls or by defects in the roll surfaces.

Tool marks and scratches in duralumin come primarily from the methods of fabrication used. Careful handling and workmanship will avoid an excess of both.

Coiled sheet is sometimes received with a line of imperfections down the center. These imperfections resemble corrosion pits and are due to the method of heat treating such dural-

umin coils. The coiled sheets are readily heat treated in the salt bath by having an aluminum wire separate the various layers of the coil. This aluminum wire apparently causes more or less pitting of the sheet while it is in the bath. Improved methods have obviated this defect.

Rivets are manufactured from both drawn and extruded wire. In certain cases one suits where the other does not. The most common defect in the manufactured rivet as received is cracking the head. Where cracked heads are few and far between it is nearly an impossibility to avoid getting some into the finished aircraft, for as a rule the cracks are so fine that the greatest care is necessary to be sure there is a defect. In practically all rivets as they are now made there is a small area in the center of the head which is rough. This rough spot may or may not be a source of trouble; but it has been noted in induced corrosion tests that this point is usually more active than the other parts of the rivet. It is desirable for the rivet manufacturers to correct as is the question of cracked rivet heads.

The most common serious defect in duralumin being fabricated into parts is a crack. These cracks are primarily due to stressing the material by working it too long, too cold, or too hard. They are frequent on parts drawn or pressed or shaped and extended in size from very minute cracks to complete parting of the material. Sheet bent on a very small radius in proportion to the thickness of the material will tend to crack inside



and outside. The size of the cracks or their frequency determines whether or not the material can be used for the purpose intended. In some rare cases the constitution of the material is responsible for the cracks but in most cases it is due to the design or to the shop process. Sheets usually show cracks if at all at sharp bends. Forgings may show cracks at sharp bends or in any part that has been worked too cold. Metal propellers should be inspected with a magnifying glass to be assured that no cracks exist. Etching duralumin in a caustic soda solution will tend to make cracks more apparent and is a procedure resorted to for inspection purposes in forgings.

Scratches, buckles, blisters and tool marks in duralumin are other defects that occur in the fabrication of parts. Scratches and tool marks are largely avoidable by proper care in handling. No particular advantage accrues to rubbing out these defects with emery cloth or steel wool.

#### Buckles Can Be Prevented

Buckles can be prevented if desired by quenching the part in an air blast instead of water or oil. Buckles will be the most severe in the case of most rapid cooling which in practice is by quenching in cold water. The working out of buckles within a short time after the heat treating operation is a common practice and is not known to be injurious to the material. Some method of stretching the sheet into place on aircraft sur-

faces would be of great advantage from the appearance point of view. With the present methods in use, the buckles in the sheets on surfaces are so open to vibration and appearance objections that fabric maintains its position as a wing covering.

In discussing the question of rivets further it might be mentioned that defective rivets are, so far as the aircraft industry is concerned, up to the riveter. Each rivet passes through the hands of the riveting crew and is open to their inspection both before and after being driven. Cracked heads and cracked points are readily discernible to this crew and their whole-hearted support is necessary to insure good joints. There is another factor connected with rivets which demands attention in assembly work and that is the question of lining up the rivet holes. Correct bolting-up and reaming are essentials. The complete driving of the rivet so as to fill the hole is a matter worth detailed attention. The flow obtained with properly heat-treated rivets is considered to be good. In general, practically anything within reason can be done with duralumin rivets but a clean job is usually the result of the care that should be taken to this phase of assembly work.

A defect readily produced in duralumin by the anodic oxidation treatment is that of burning the metal by using too great a current density. Duralumin which has been so burned is very weak and will not serve any useful purpose. The prevention is dependent entirely on the current control during



the treating operation.

### Proper Heat Treating Essential

When the aircraft designer specifies duralumin for a part it is done with a view to having material that comes up to certain physical or mechanical values. It is therefore incumbent on those working to that design to produce the final piece with all operations leading toward that ultimate. Perhaps the easiest place to make errors that will alter the desired results materially is in not having properly heat-treated duralumin in the final assembly. Annealed and cold-worked duralumin will both find their way in as heat-treated material unless care is taken by rigid inspection. The simplest arrangement to check the parts is by means of the scleroscope. Properly heat-treated and aged duralumin will give a scleroscope hardness of about 38 whereas the annealed material will give a value considerably lower, and cold-worked slightly higher. To be more certain than the hardness values will indicate, bend tests should be combined with the hardness determinations.

Duralumin which has been burned in the thermal treatment is readily discernible to the eye. Extreme brittleness is a noteworthy feature in material which has been too hot. There is no recovery for a burned piece of duralumin.

In conclusion it can be stated that the amount of duralumin rejected due to defects and failures is not great compared to

the quantities thrown out in other aircraft material; but there is continually the possibility that an undesirable piece will find its way into the finished airplane so it is essential that due diligence be exercised by those in control of this feature.



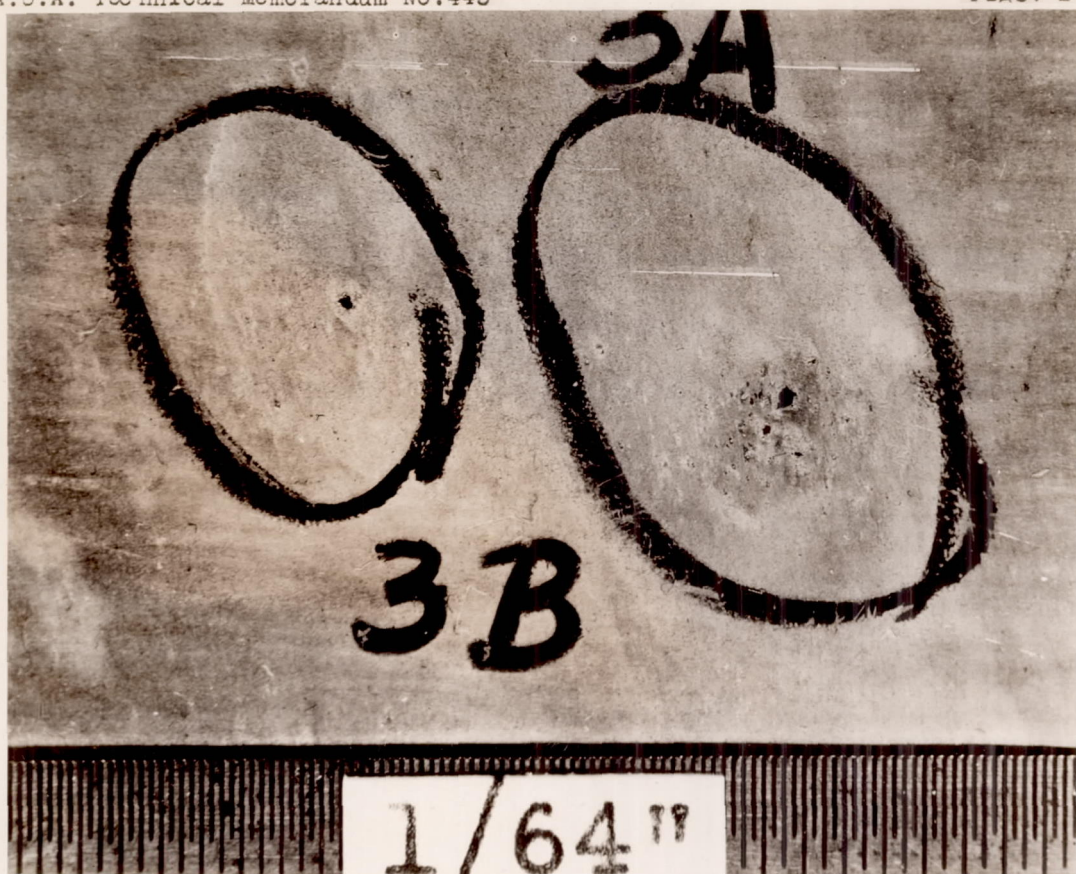


Fig.1 Inclusions in a duralumin sheet. Photograph is slightly magnified

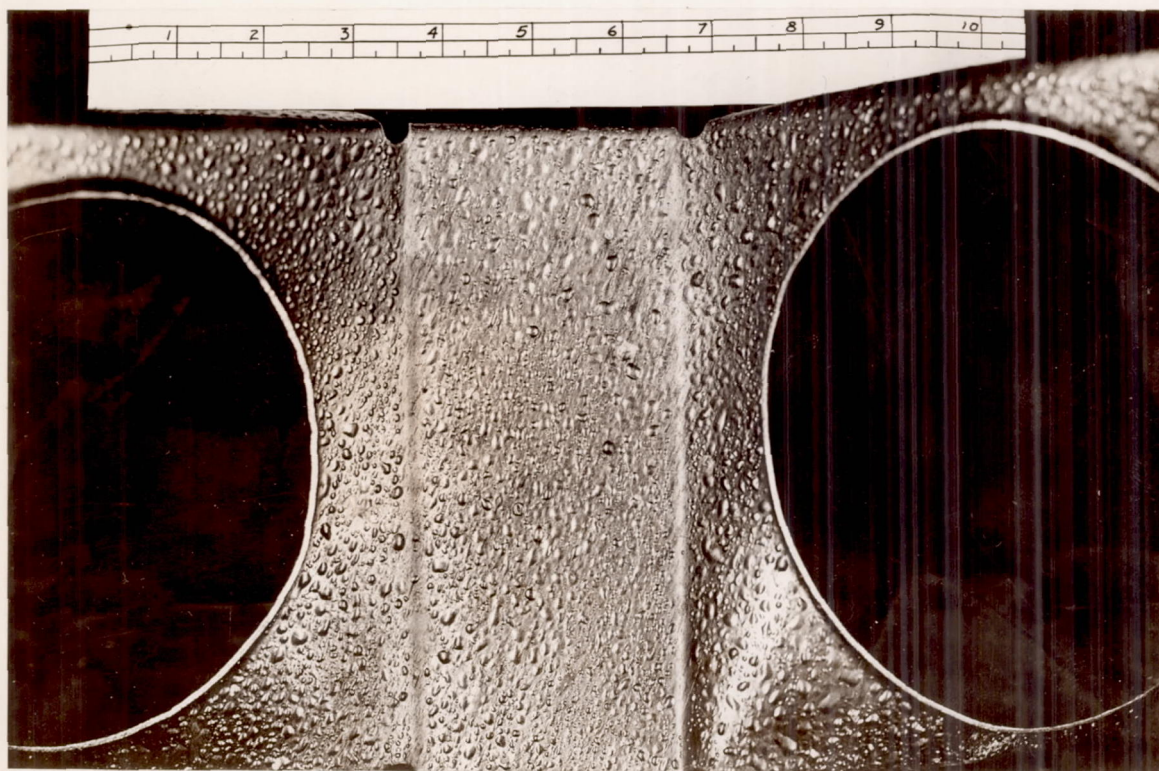


Fig.2 Duralumin blistered by overheating in heat treatment 6290 A S



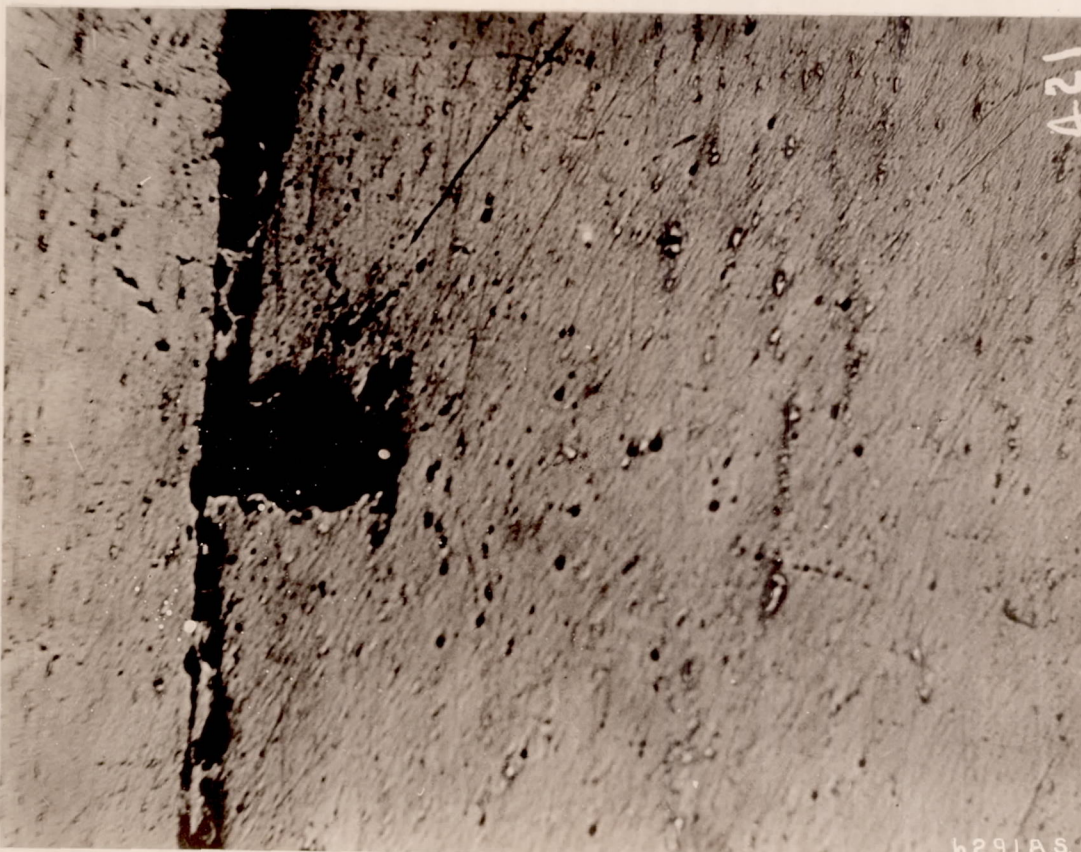


Fig.3 A pit resulting from the removal of an inclusion in a duralumin sheet. Photograph highly magnified.

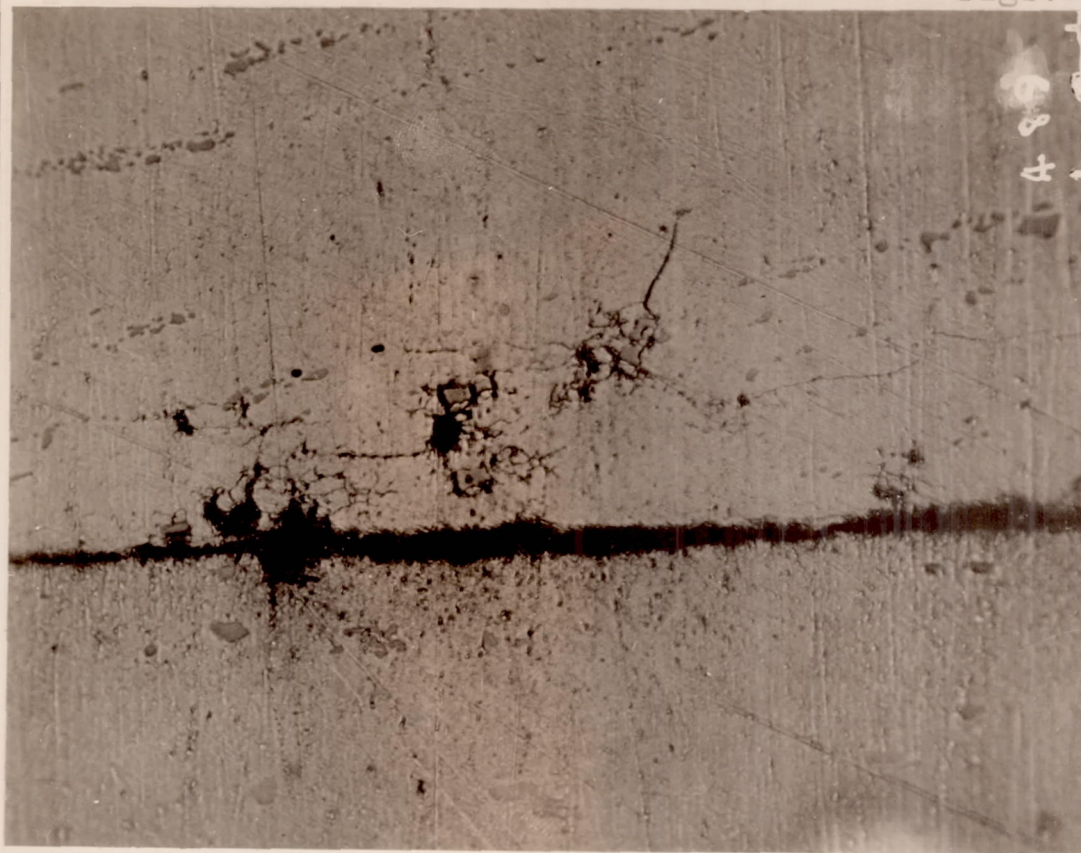


Fig.4 Cracks in and near the surface due to improper working of the metal.

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